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Missoula Flood Deposits in Kittitas County

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Abstract

The Missoula Floods of the late Pleistocene were a major factor in the creation of the landscape of Central Washington. Much research has been done on the Missoula Floods from the Columbia River east, but little has been done to identify flood deposits in Kittitas County. As a result, there are no maps showing the upper limits of the flooding or the types of sediments deposited by the Missoula Floods for this county.

The purpose of this research was to map the upper limits of the Missoula Floods in a portion of eastern Kittitas County, date the flood deposits, and identify and describe the types of deposits found within these limits.

The methods used in this research include: 1) field reconnaissance; 2) analysis of air photos; 3) field checking; 4) field mapping and surveying; 5) use of soils maps; 6) tephra analysis; and 7) transfer of field mapping.

Mapping of the upper limits of the Missoula Floods indicates that the maximum elevation reached by the late Wisconsin floods was 1200 feet. This elevation is based on the mapping of ice-rafted erratics, which were found to be the best indicator of maximum flood levels. Other flood deposits found in the study area were giant gravel bars and laminated sand and gravel deposits. Flood deposited sand is found at a maximum elevation of 1100 feet. The lack of fine slack-water sediments at elevations higher than flood deposited sand can be explained by several possibilities, including subsequent erosion. Tephra analysis provided no evidence that any of the flood sediments found in the research area were older than the late Wisconsin flooding episode. The repetitive sequences of laminated sand and gravel that were found in the research area did not provide evidence of multiple floods during the late Wisconsin episode of flooding.

This research is significant because it provides an accurate spatial representation of the extent of the Missoula Floods in part of eastern Kittitas County, as well as insight into timing of the floods, and the characteristics of the flood sediments and deposits. This could be useful in understanding the natural landforms and cultural features of the area.

Introduction

The Missoula Floods of the late Pleistocene were a series of the largest floods known to have taken place on this planet (Baker, 1973). These floods were the result of the rapid draining of a huge glacial lake, known as Lake Missoula, that existed for 2000-3000 years during the late Wisconsin glaciation (Atwater, 1986). The rapid draining of glacial Lake Missoula produced the erosional and depositional features of the region of eastern Washington known as the Channeled Scablands.

The idea that the landscape of the Channeled Scablands originated as the result of gigantic floods was first conceived by Professor J. Harlen Bretz of the University of Chicago. In 1923 Bretz began a series of papers suggesting that the Columbia Plateau had been swept by a cataclysmic flood. His hypothesis was not accepted by the geologic community of the time, and provoked many alternative theories explaining the unique geomorphology of the area. Bretz based his flood hypothesis on the geomorphic field evidence that he found, however, he was unable to provide an acceptable explanation for a source of the huge volume of water necessary to sustain a flood of such great proportions. Eventually, with the help of evidence presented by Pardee (1942), glacial Lake Missoula was identified as the source of the flood waters. It was not until 1956 that Bretz's "outrageous hypothesis" was widely accepted. In a report submitted in 1956, Bretz soundly refuted the opposing theories and presented new evidence that up to six great floods had occurred (Baker and Nummedal, 1978). Since that time evidence has steadily accumulated in support of Bretz's gigantic flood theory, including evidence that dozens of floods may have actually occurred (Waitt, 1994).

When the Missoula Floods crossed the Columbia Plateau, or coursed the Columbia River channel, they eventually met constrictions posed by the passage of preflood drainage channels through the anticlinal ridges of the western Columbia Plateau. Flood waters became ponded upstream of these constrictions, creating relatively low-energy flood areas where sediments were deposited (Baker, 1973). One such constriction was Sentinel Gap in the Saddle Mountains, five miles south of the research area.

Problem

While there has been much research done on the Missoula Floods in Washington State from the Columbia River east, little has been done to identify flood deposits in Kittitas County. As a result there are no maps showing the upper limits of the Missoula Floods or the types of sediments deposited by the floods in this county.

Purpose

The purpose of this research was to map the upper limits of the Missoula Floods in a portion of eastern Kittitas County, date the flood deposits, and identify and describe the types of flood deposits that occur within those limits.

Significance

This research is significant because it provides an accurate spatial representation of the extent of the Missoula Floods in Kittitas County, as well as insight into timing of the floods and the characteristics of the flood sediments and deposits. This information could be useful in understanding the natural landforms and cultural features of this area.

The Research Area

The research area is located on land administered by the Ginkgo Petrified Forest State Park and the Yakima Training Center. This area lies to the west and south of Vantage (SE1/4, S19, T17N, R23E, Willamette Meridian), Washington, which is located at approximately 46^{o} 57' North, and 119^{o} 59' West (see fig.1). The elevation of the research area ranges from 570 feet at the surface of Wanapum Lake on the Columbia River, to 1700 feet, the highest elevation explored during the field reconnaissance. The

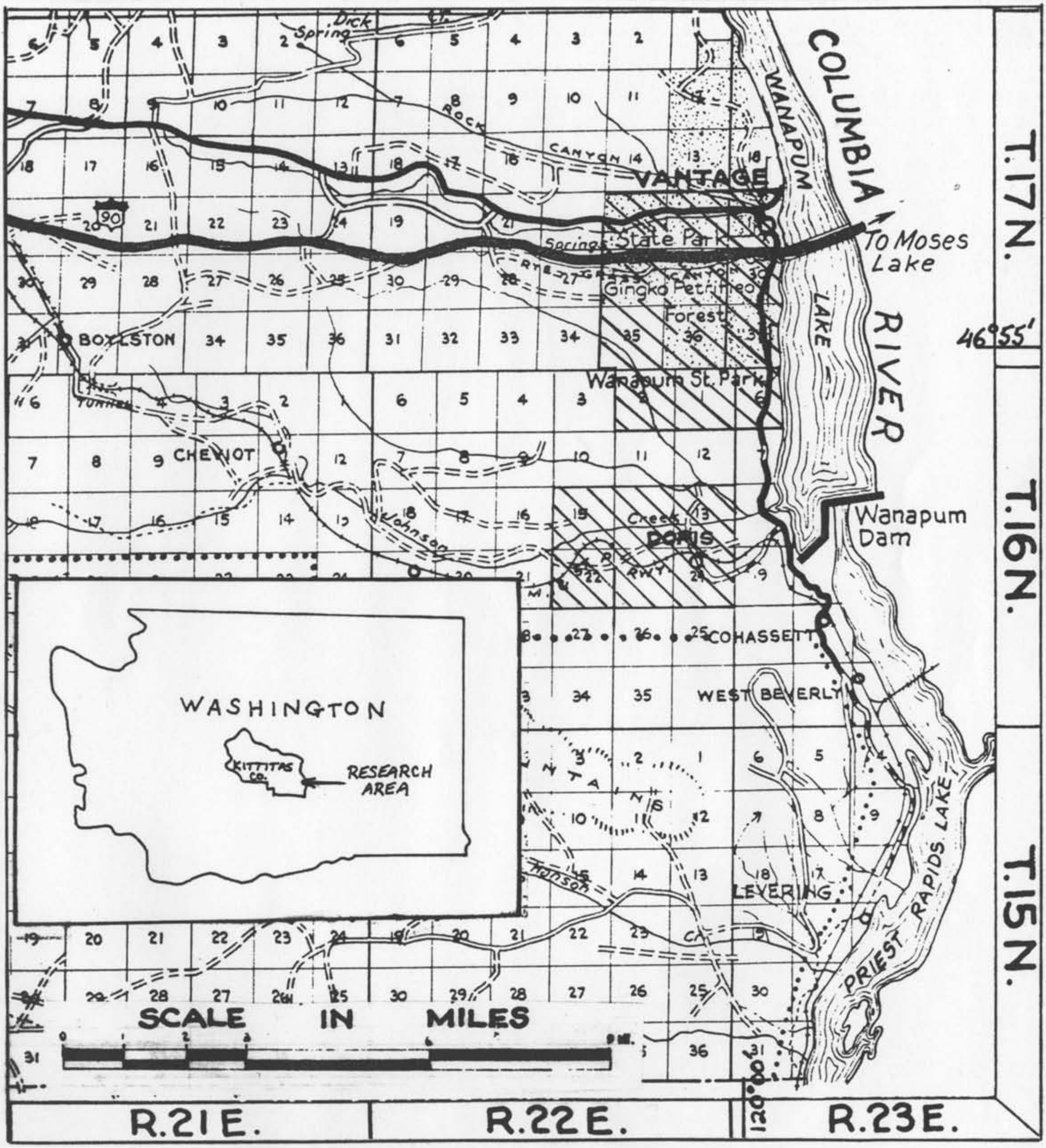


Figure 1. General location map for the research area.

area considered by this research includes that part of Kittitas County lying south of the Vantage Highway in Schnebly Coulee; north of the unnamed ridge to the north of Middle Canyon; and west of the Columbia River as far as necessary to include all flood deposits. Included in the research is a separate area where the initial field reconnaissance was conducted. The field reconnaissance was carried out in an area of several square miles near the former town of Doris (NE1/4, S24, T16N, R22E). Maps used are primarily the Ginkgo and Doris 7.5 minute U.S.G.S. topographic quadrangles.

Literature Review

Much evidence exists that multiple Missoula Floods have scoured the Channeled Scablands and coursed the Columbia River channel. Although the types of sediments produced by these floods are well known, the timing and size of the floods are subjects that are still open to scientific debate. Following is a brief review of previous work that pertains to this research.

Evidence of multiple floods

The first to recognize evidence of multiple Missoula Floods was Bretz (1956). Bretz recognized geomorphic evidence for as many as six cataclysmic floods. Later, Waitt (1980) used slack-water sediments to develop the hypothesis that at least 40 separate floods had emanated from glacial Lake Missoula, each leaving a separate layer of fine sediment (rhythmite) in the Walla Walla Valley. This hypothesis was supported by the findings of Atwater (1986) who correlated alternating flood beds and lacustrine deposits in the Sanpoil River Basin with regularly repeating outburst floods of Glacial Lake Missoula. Atwater (1986) found evidence of a total of 89 Lake Missoula floods, and inferred that about 100 floods actually occurred. He suggested that the difference in the number of floods implied at the Walla Walla and Sanpoil sites is due to the difference in flood depths necessary to flood each site. In other words, many of the smaller late Wisconsin floods that are recorded in the Sanpoil River basin site did not flood the Walla Walla Valley site.

Baker and Bunker (1985) suggested that Waitt's hypothesis was based on too many unverified assumptions, including the theory that each rhythmite was deposited by a separate flood. Work done by U.L. Moody (1987) indicates that, in at least some cases, one flooding episode produced more than one rhythmite. This conclusion was achieved by the correlation of flood sediments, using St. Helens Set S tephra as a stratigraphic marker. This concurs with the findings of Smith (1993), who concluded that the deposition of one rhythmite per flood was the norm but not the rule.

The most reasonable conclusion seems to be that there were many late Wisconsin flooding events, perhaps as many as 100. The differences in magnitude have probably resulted in marked differences in deposition patterns, so that evidence present in one location may be missing in another. The deposition patterns are further complicated by the various routes taken by the floods. These investigations cover only the latest period of flooding that occurred during the late Wisconsin glaciation. Other investigations indicate that similar periods of flooding may have accompanied each glaciation of the late Pleistocene.

Timing of the floods

The most well known of the Missoula Floods are those that occurred between 16 and 12 ka during the late Wisconsin glaciation (McDonald and Busacca, 1988). During the late Wisconsin glaciation as many as 100 outburst floods of various intensities occurred. Radiocarbon dating and varve counts indicate that these floods occurred between 16,000 and 12,400 B.P., and spanned a period of 2,000 to 3,000 years (Atwater, 1986). This range is in close agreement with the 17,000 to 11,000 B.P. time frame deduced by Waitt (1985). Less well known are floods that occurred during previous glaciations.

Patton and Baker (1978) describe stratigraphic evidence of both late Wisconsin and pre-Wisconsin flooding of the Cheney-Palouse Scabland. They interpreted flood gravel deposits interstratified with loess deposits and paleosols to conclude that "extensive catastrophic flooding occurred throughout the eastern Columbia Plateau in pre-Wisconsin time". Their work has been extended by McDonald and Busacca (1988, 1992), who found a record of "multiple episodes of giant floods older than those of the late Wisconsin" preserved in the loess deposits of eastern Washington. McDonald and Busacca (1988) define an "episode" as one to many outburst floods that may have spanned a period of several thousand years. Using periods of loess deposition, identifiable paleosol formations, and tephra deposits to correlate flood deposits, Mc Donald and Busacca (1988) identified five separate flooding episodes older than that of the late Wisconsin. McDonald and Busacca (1992) used the datable correlations, such as tephras of known age, to assign broad bracketing dates to some of the pre-late Wisconsin flooding episodes. These episodes occurred between 35,000 and 80,000 B.P., and 130,000 and 200,000 B.P.. Paleomagnetic measurements indicated that one of the episodes occurred more than 790 ka (Mc Donald and Busacca, 1988). Mc Donald and Busacca (1988) conclude that glacial outburst floods, similar to the Missoula Floods of the late Wisconsin, scoured the Channeled Scabland during many Pleistocene glaciations.

Size of the Floods

When the Purcell Trench lobe of the Cordilleran ice sheet blocked the Clark Fork river during Pleistocene glaciations, up to 2500 cubic kilometers of water backed up behind the ice dam to form glacial Lake Missoula (Waitt, 1994). Based on field evidence and step-backwater flow modeling, O'Conner and Baker (1992) estimated a peak discharge of about 17 million cubic meters/second near the point of release. Waitt (1980) proposed that this huge volume of water was released in a series of jokulhlaup events, with the lake refilling after each event. Evidence supporting this theory was presented by

Atwater (1986), who found stratigraphic evidence of regularly recurring floods that he attributed to a self-dumping Lake Missoula. Atwater (1986) used varve counts to show a maximum of 55 years between flood events, with the latest floods being more frequent. Based on the relative thicknesses of the flood beds, Atwater concluded that the size of the floods decreased as their frequency increased.

A similar model of Missoula flooding is implied by O'Conner and Baker (1992) who used evidence of peak flood stages to estimate maximum Lake Missoula flood discharges. They propose that, based on a maximum Lake Missoula capacity of 2,184 cubic kilometers, at least one outburst flood must have been more catastrophic than the jokulhlaup type releases proposed by Waitt. O'Conner and Baker (1992) postulate that a sudden complete failure of the Lake Missoula ice dam resulted in a large catastrophic flood that was later followed by a series of smaller jokulhlaup events.

Evidence of flooding used to define maximum flood levels include eroded loess scarps, flood deposited sediments, minor divide crossings, and ice-rafted erratics (Baker, 1973). These indicators were used by Baker (1973) to build a water surface profile for peak discharges of the largest late Wisconsin floods. Baker's (1973) data implies a maximum flood level of 1200 feet for the study area based on an erratic (1180 ft.), a highest divide crossing (1190 ft.), and a highest divide not crossed (1210 ft.). Baker (1973) states that eroded loess scarps and flood deposited sediments do not make accurate maximum flood level indicators because they can be covered by an unknown depth of water. They do, however, provide useful minimum flood depth indicators. Minor divide crossings and ice-rafted erratics are listed by Baker (1973) as reliable high-water mark indicators.

Types of sediments deposited by the floods

The types of sediments deposited by the Missoula Floods can be separated into the two broad categories of channel deposits and slack-water deposits. Channel deposits include pendant bars, eddy bars, and expansion bars. These are coarse-grained flood bed-load materials that are deposited as subfluvial bars (Baker, 1973). Pendant bars occur immediately downstream of obstructions, and are smooth streamlined mounds of flood gravel. Expansion bars occur where flood waters decelerate in an expanding channel, often downstream of a constriction. Eddy bars formed in the mouths of tributary valleys adjacent to high velocity flood channels, and are present in the study area. Because these giant gravel bars are deposited subfluvially, they are not useful as indicators of maximum flood level.

Slack-water sediments consist of rhythmic sequences of laminated silts and sands that are deposited in valleys that are tributary to the main flood channel. These sediments generally fine up-valley, suggesting a decrease in competence in the up-valley flood currents (Baker, 1973). Baker (1973) offers the hypothesis that "the coarsest material would be deposited as an eddy bar at the junction of the tributary and the main channel. Farther up the valley, sands and silts would settle out as fining-upward *turbidite*....The result of successive surges would be a vertical sequence of numerous *turbidites*...". *Turbidites* are sediments deposited by a turbidity current, and are characterized by graded bedding, moderate sorting, and well developed lamination (Bates and Jackson, 1984).

Ice-rafted erratics are another type of Missoula Flood deposit. These are generally crystalline rocks that were transported in glacial icebergs. The icebergs were probably part of the glacial dam itself, and rode high atop the flood surges (Smith, 1993). The icebergs became stranded on valley walls where they melted, depositing their load of erratics. Smith's (1993) model of ice-rafted erratics varies significantly from Baker's (1973) in that Smith maintains that the highest erratics were deposited by flood surges. Baker (1973) describes the erratics as being deposited in areas where flood waters were locally ponded. Although this difference may have important implications for hydrologic modeling, for the purposes of this research it should be sufficient to conclude that ice rafted erratics provide a marker for maximum elevations reached by the floods.

Methodology

The methods used in this research include: 1) field reconnaissance of the study area in order to identify deposits known to have originated from the Missoula Floods; 2) analysis of air photos; 3) field checking of features noted on air photos; 4) field mapping and surveying of erratics; 5) use of soils maps to identify flood sediments; 6) tephra analysis to determine the chronology of sediment layers; and 7) transfer on to 7.5 minute U.S.G.S. topographic quadrangles.

Field reconnaissance

A field reconnaissance of the study area was conducted in order to identify flood deposits known to have originated from the Missoula Floods. This initial field reconnaissance was conducted just north of the Saddle Mountains in the area of Doris (NE1/4, S24, T16N, R22E). The reconnaissance was carried out over the period of several field excursions, and the area was explored to a maximum elevation of 1700 feet. This was done in an attempt to locate any flood deposits that might be higher than the 1200 foot elevation calculated by Baker (1973).

Analysis of air photos

Air photo stereopairs of the research area were analyzed using a pocket lens stereoscope and a hand lens to identify flood sediments. The photographs used were 1:12,000 scale color photos shot in 1984/1985 by the Washington State Department of Natural Resources. Large features such as sand and gravel deposits and slumps could be recognized in some areas on the air photos, however, smaller features such as erratics were not visible.

Field checking of features noted on air photos

Field checking of features noted on air photos was accomplished on foot. Features that appeared as possible slack-water sediment deposits were examined first hand on the ground. Linear changes in color that appeared as possible paleoshoreline marks were also examined on the ground.

Field mapping and surveying of erratics

Field mapping of erratics was done on foot using a 7.5 minute U.S.G.S. topographic quadrangle, Brunton pocket transit, and an altimeter. The entire research area was covered on foot at an elevation of approximately 1200 feet, in an attempt to locate erratics at the highest elevation. Once erratics were located, their positions were determined using the topographic quadrangle. Elevations were checked against the topographic quadrangle using the altimeter.

The topographic quadrangles used have a contour interval of 20 feet, thereby introducing an approximate margin of error of 20 feet in elevation. Random needle fluctuation of the altimeter was approximately 5 meters (16.4 feet), on top of variations due to gusting wind and changing barometric pressure. The topographic quadrangle was therefore used as the primary locator, with the altimeter used as a backup for elevation. The Brunton pocket transit was used occasionally to check position.

The accuracy of field mapping was checked by the use of a geodetic total station. The instrument was referenced to a benchmark on the Vantage Highway (SE1/4, NW1/4, S24, T17N, R22E, elevation 894 ft.) and several mapped erratics with direct line of sight from the road were surveyed for location and elevation. These produced a maximum error in elevation of 12.3 feet, and a minimum error of 3.7 feet, well within the 20 feet margin of error expected.

Several interesting patterns were noticed while field mapping erratics. Erratics were often found in small clusters, and were most commonly found on gentle slopes or flat areas. Erratics were often partially or completely buried by loess on north facing slopes.

Erratics were most easily found on south facing slopes where weathered basalt was exposed and free of loess.

Use of soil survey maps

Soil survey maps for Kittitas County (unpublished) were used to identify possible Missoula Flood sediments at elevations higher than 1200 feet.

Tephra analysis

Tephra analysis was used to determine the chronology of flood sediments exposed in a roadcut on the Vantage Highway (SE1/4, NW1/4, S24, T17N, R22E, elevation 920 feet). The analysis was performed by the GeoAnalytical Laboratory of Washington State University. The two samples tested were numbered WA-GINK-6-19-98-(1) and WA-GINK-6-19-98-(2).

Transfer of field mapping

The results of field mapping were transferred to 7.5 minute U.S.G.S. topographic quadrangles. Individual mapped erratics were marked with dots and the inferred upper limit of the Missoula Floods is marked with a dashed line .

Results and Discussion

Extent of the flooding

During the field reconnaissance several large granitic erratics were discovered (see fig. 2), as well as many smaller erratics, granitic sand, and giant gravel bars. Although granitic erratics were found to be very common in the Doris area, no erratics were found above the 1200 foot elevation.

A large flood-laid deposit of granitic sand, gravel, and cobbles (see fig. 3) was found in the unnamed tributary canyon immediately south of Johnson Creek (SE1/4,

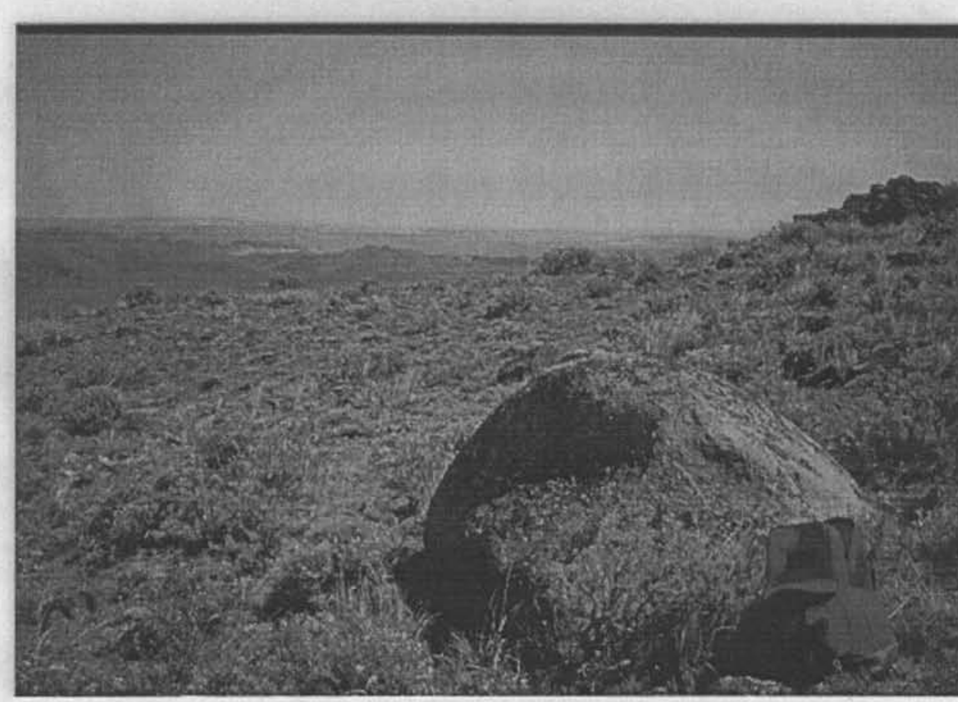


Figure 2. Large iceberg-rafted erratic deposited by the Missoula Floods. Doris area of the Yakima Training Center (NE1/4, S24, T16N, R22E). Note backpack for scale.

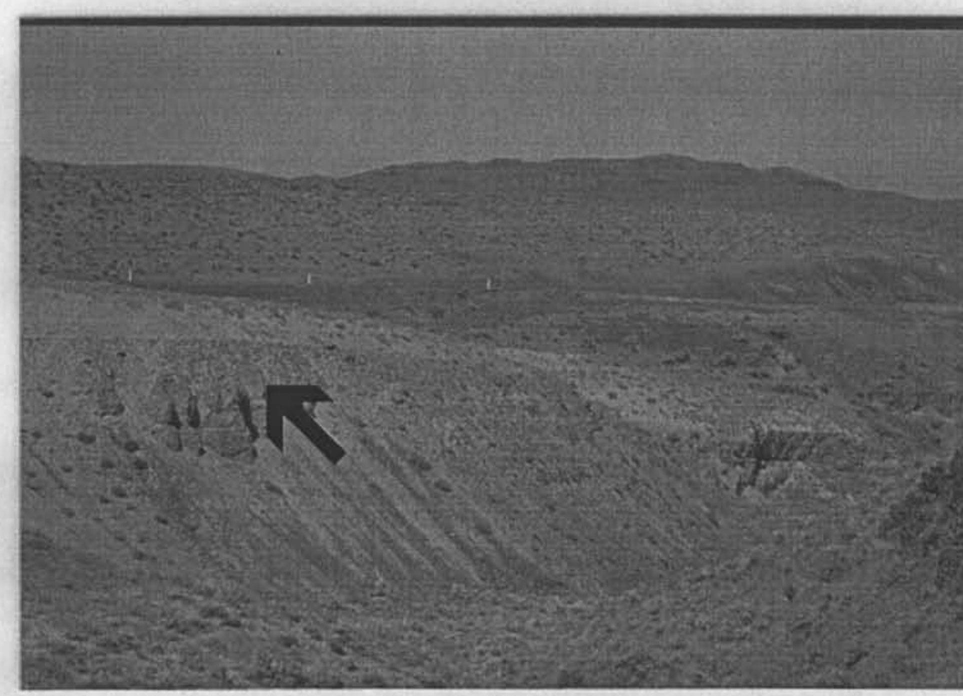


Figure 3. Missoula Flood deposits in the lower Johnson Creek area of the Yakima Training Center (SE1/4, NW1/4, S13, T16N, R22E). These are repetitious laminated beds of sand, gravel, and cobbles.

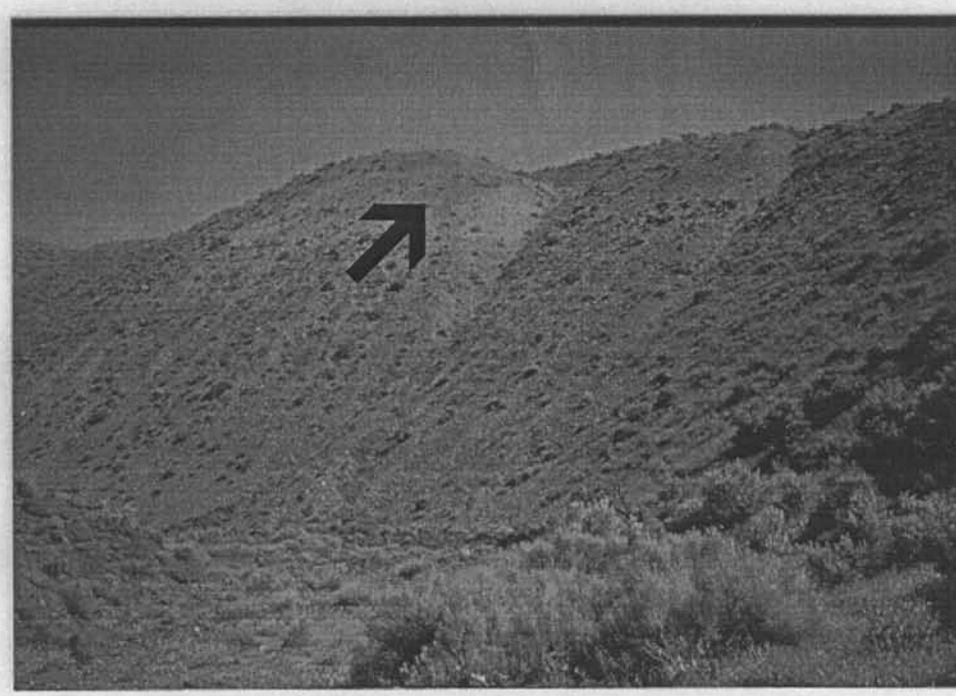


Figure 4. Flood deposited giant gravel bar in the lower Johnson Creek area of the Yakima Training Center(E1/2, S13, T16N, R22E).

NW1/4, S13, T16N, R22E). This deposit is comprised of repetitious laminated beds of sand, gravel, and cobbles. The flood deposited sand that caps this formation reaches a maximum elevation of 1100 feet, and overlies bedrock further upstream. A giant gravel bar (E1/2, S13, T16N, R22E) lies just down-valley of this deposit and reaches a maximum elevation of 1060 feet (see fig. 4). No slack-water sediments were found above the 1100 foot elevation of the sand deposit.

Giant gravel bars were also visible on the air photos, near the mouths of tributary valleys. These giant gravel bars appeared as flat-topped terraces (see fig. 5). Where granitic sand was exposed, the deposits were visible on the air photos as light colored exposures in cut banks and road cuts (see fig. 5). Where little erosion has occurred and vegetation has stabilized, sand and gravel deposits were difficult to distinguish from loess covered basalt.

Paleoshoreline-like features were visible on the air photos. They appeared as linear changes in color near the 1200 foot elevation. These linear features proved to be changes in vegetation, but they did not appear to be the result of shoreline erosion or deposition. It is likely that these vegetation patterns are due to changes in slope and associated differences in soils. Also, these features were not always horizontal and occurred at varying elevations, further disproving them as shoreline features.

Light colored deposits that appeared to be possible slack-water sediment terraces were visible near the 1200 foot elevation along Interstate 90 (E1/2, NE1/4, S27, T17N, R22E). These features were field checked and determined to be exposed interbed material and a roadside accumulation of the most recent Saint Helens ash.

The air photos were also used to identify large scale slumps that were first noticed from the ground (see fig. 6). These slumps often coincide somewhat with the 1200 foot elevation, and could be related to the Missoula Floods.

Soils were considered as possible indicators of the upper limits of the Missoula Floods. Of primary interest were soils developed in slack-water sediments such as the

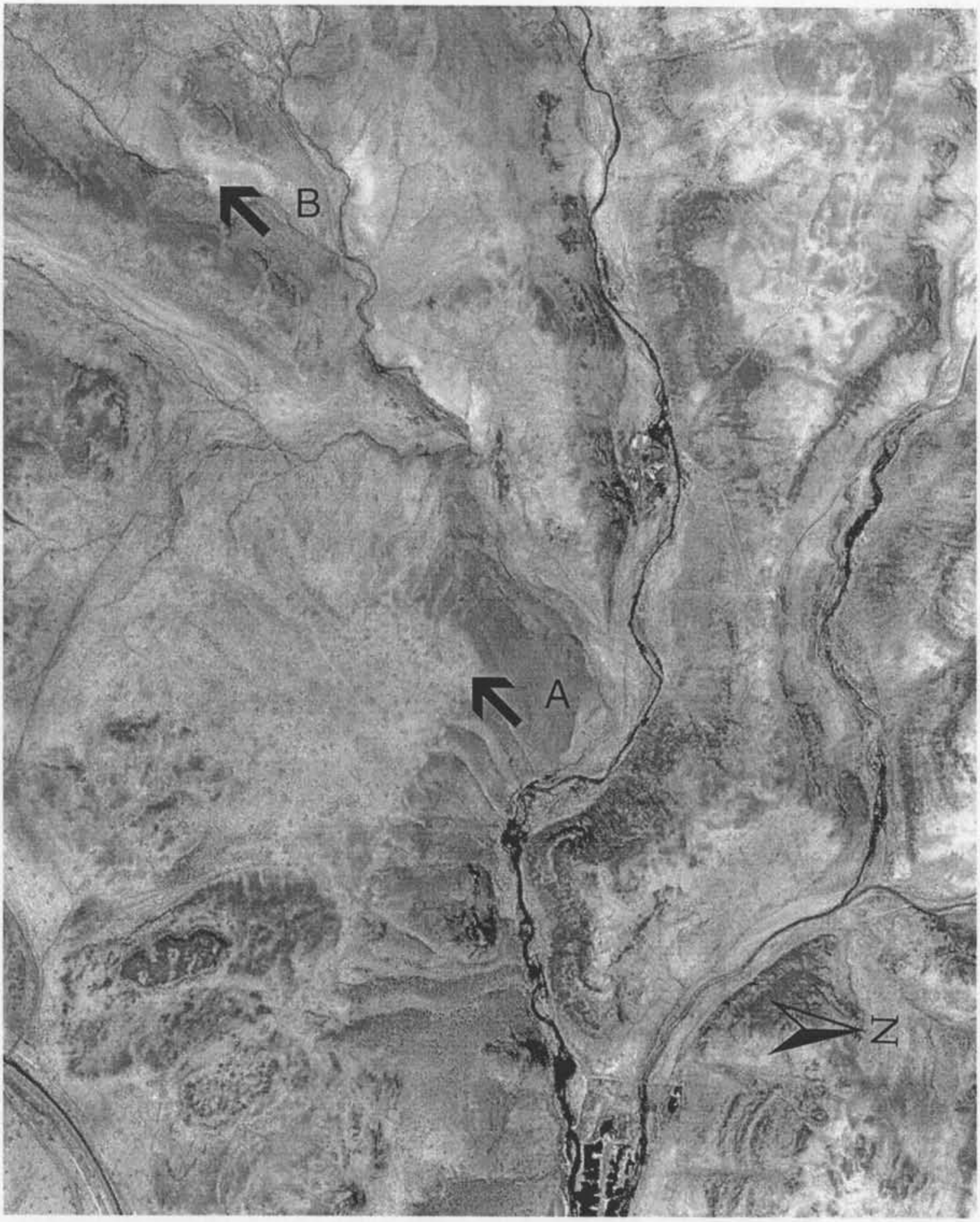


Figure 5.
Missoula Flood sediments in the lower Johnson Creek, Yakima Training Center area. 'A' refers to a giant gravel bar (E1/2, S13, T16N, R22E). 'B' refers to fluvially deposited granitic sand (SW1/4, NW1/4, S13, T16N, R22E).
Washington Department of Natural Resources Air Photo #SC-C-85 38-078-032
Scale 1:12000.

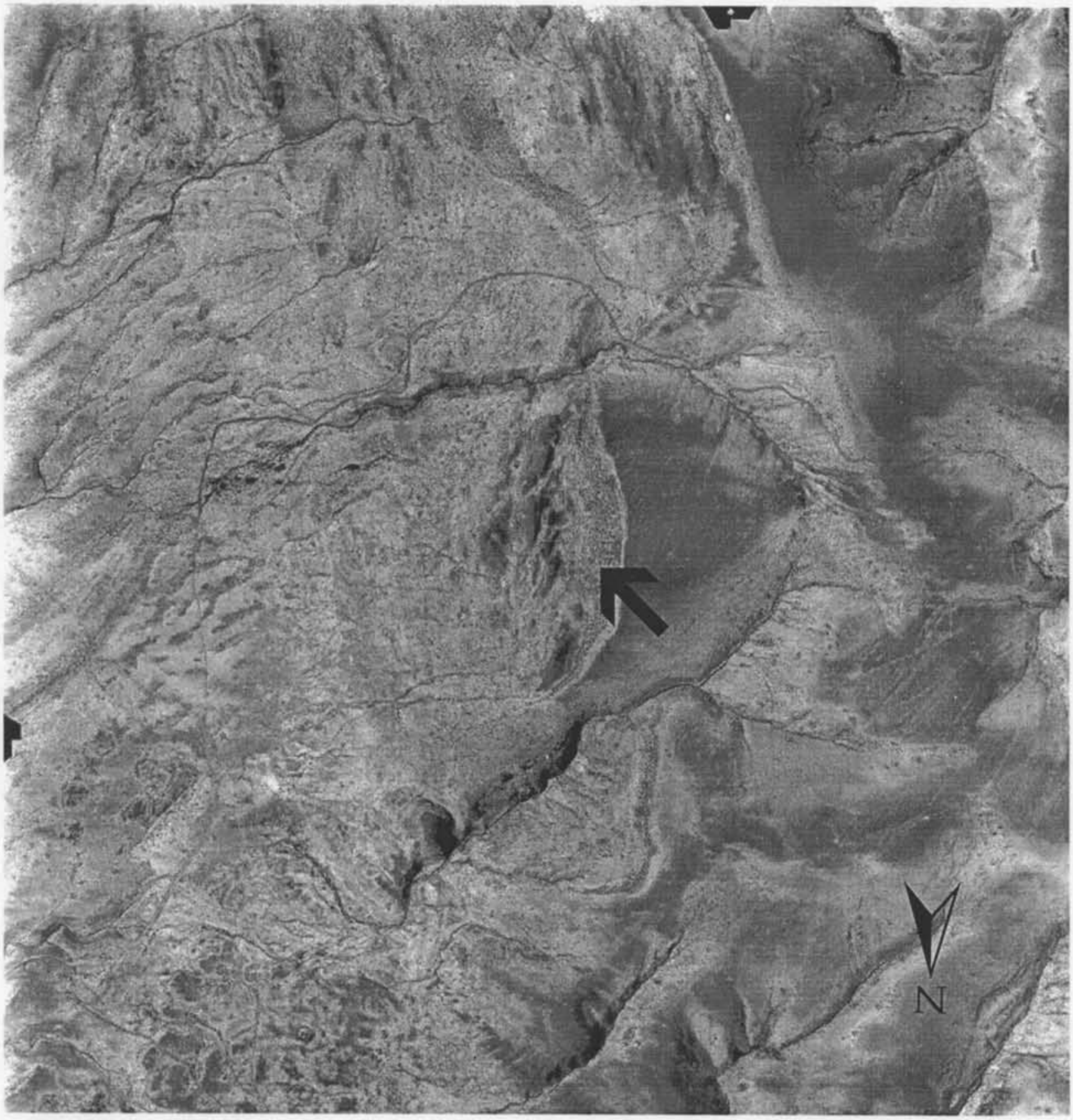


Figure 6.
Example of a large slump, possibly caused by the Missoula Floods. Ryegrass Mountain, Ginko Petrified Forest State Park area (SE1/4, S36, T17N, R22E). Washington Department of Natural Resources Air Photo # SC-C-85 29-078-044 Scale 1:12000.

Sagehill series described by Herman Gentry (oral communication, 1998) of the Soil Conservation Service. These soils are formed in lacustrine deposits with a mantle of loess (U.S.D.A. Soil Conservation Service, 1984). The unpublished Kittitas county soil survey maps depict two Sagehill series soils units in the study area at elevations above 1200 feet. These two sites were examined for flood sediments.

A Sagehill-Burbank-Malaga complex is mapped at the 1500 foot elevation along the Vantage Highway (NW1/4, SW1/4, S21, T17N, R22E). This site was examined for flood sediments in a road cut that occurs upslope at the 1600 foot elevation. Laminated bedding of quartz sand was evident in the road cut, below a significant layer of loess (approximately 5 feet). The laminations suggest lacustrine or fluvial deposition of the sand. If this is indeed a flood sediment, it is likely from an older episode of flooding, as it is buried by a significant accumulation of loess and has no associated erratics. Another explanation for this deposit could be alluvial redeposition of an eolian-transported sand. This may be a more feasible explanation, as the laminations were composed of only fine sand and silt, with no intervening layers of coarse sands or gravel. In other words, only sand of the size likely to be transported by eolian means were included in the laminations.

A Sagehill-Timmerman complex is mapped at the 1560 foot elevation at Rock Spring in Ryegrass Coulee (SE1/4, SW1/4, S21, T17N, R22E). This site was examined for flood sediments, however, no granitic or quartz sediments were found. The sediments at this site appeared to consist entirely of stratified layers of alluvial basalt gravels, silt, and loess.

Field mapping and surveying indicate that the upper limits of the largest floods that occurred during the late Wisconsin glaciation reached the elevation of 1200 feet in the study area (see fig. 7). Only two of the erratics mapped were found at significantly higher elevations, and the size, shape, and location of those two erratics suggested that they may have been Native American hammerstones. Both of these erratics were rounded and palm size. One was at an elevation of 1280 feet near the crest of a ridge; the other was at an

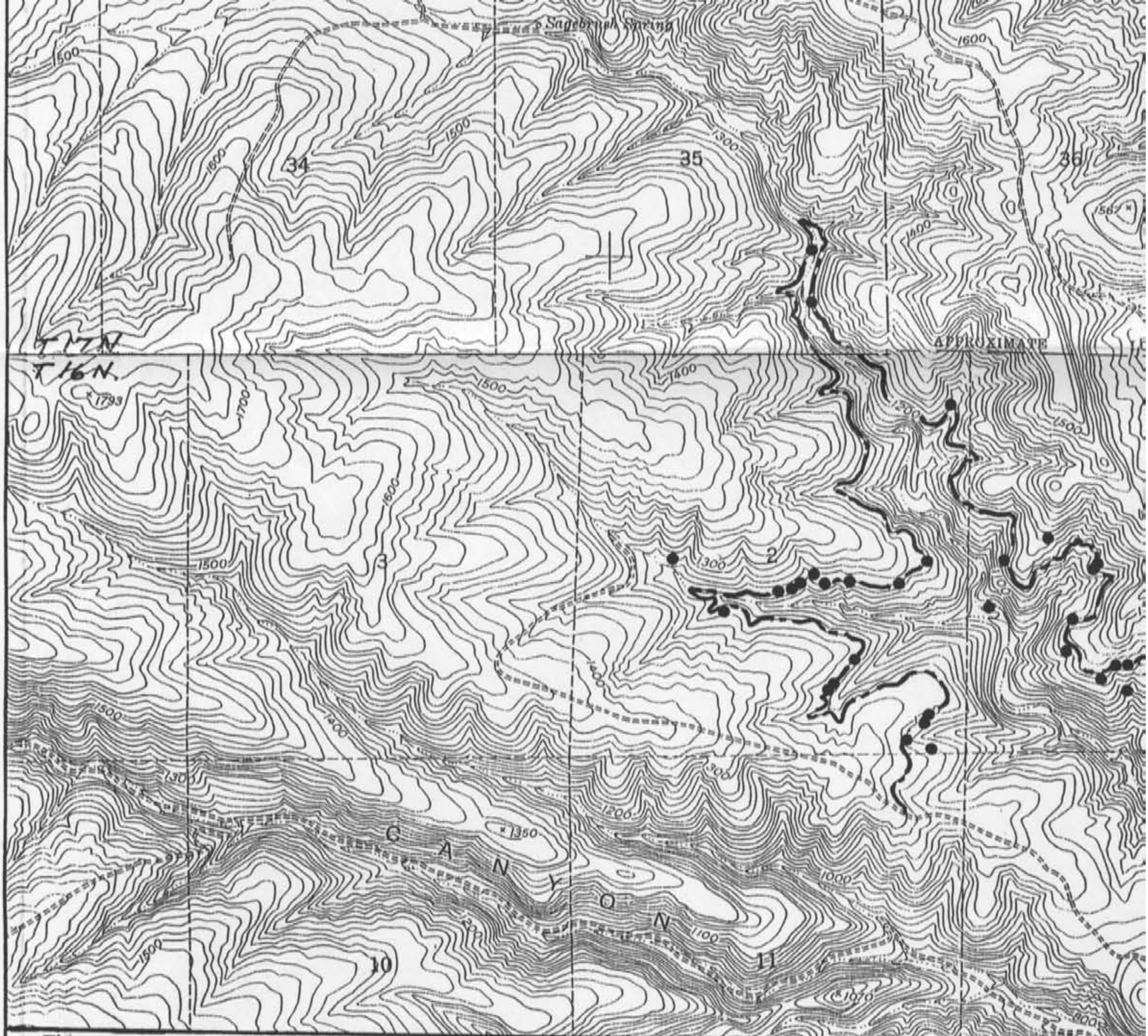


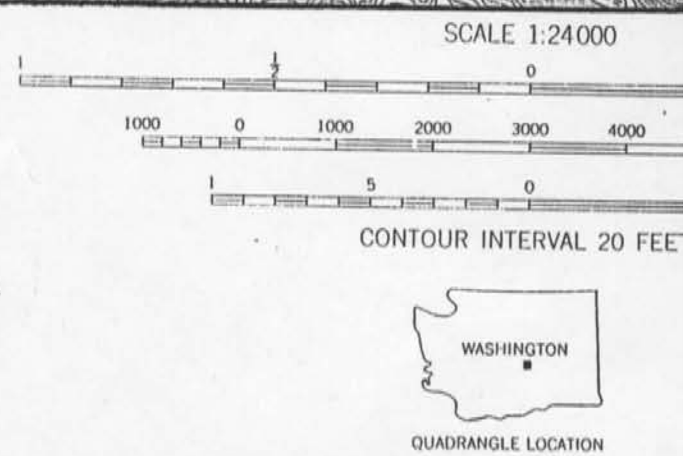
Figure 7.

Maximum elevation reached by the Missoula Floods in the research area to the west and south of Vantage, Washington.

● - ice-rafted erratics.

▬ - ▬ - inferred upper limit of the Missoula Floods.

From U.S.G.S. Ginko 7.5 minute Quadrangle.



elevation of 1260 feet near a spring. All other erratics found above 1200 feet fell within the 20 foot margin of error expected. This is consistent with the elevation of ponded flood water published by Baker (1973).

Timing of the Flooding

Tephra analysis was used to determine the chronology of flood sediments exposed in a roadcut on the Vantage Highway (SE1/4, NW1/4, S24, T17N, R22E, elevation 920 feet). This deposit is part of an old slump that has been affected by alluvial deposition and fluvial erosion. The geomorphology at this site made firm identification of stratified layers and layer boundaries extremely difficult. Two separate possible tephra deposits were identified within the feature, both of which were sampled (see fig. 8). Sample one occurs in basalt alluvium that blankets most of the feature. Sample two occurs within a coarse granitic sand/fragmented basalt deposit that underlies the basalt alluvium.

Both samples were tested by the GeoAnalytical Laboratory of Washington State University. Results indicated that sample 1 was Mazama tephra (6850 B.P.), and sample 2 was 95+% mineral detritus (not a tephra). Sample 2 contained sparse volcanic glass shards that were equally similar to both the Mount St. Helens S (12,900 B.P.) and Cw (33,650 - 37,600 B.P.) tephras. It is likely that sample 2 is a reworked Mount St. Helens tephra.

The stratigraphic position of the Mazama tephra within the basalt alluvium indicates that a period of fluvial deposition occurred around 6850 B.P., following the last flooding episode. This agrees with research done by Pavish (1973) and Cochran (1978), both of whom recognized several periods of erosion and aggradation that occurred in this region after the Missoula Floods. The position of the granitic sand deposit below the alluvium dates the flooding episode at prior to 6850 B.P.. That would agree with the general limits of 11,000 - 17,000 B.P. for late Wisconsin flooding (Waitt, 1985). The position of the Mt. Saint Helens S and/or Cw glass shards in the coarse granitic sand

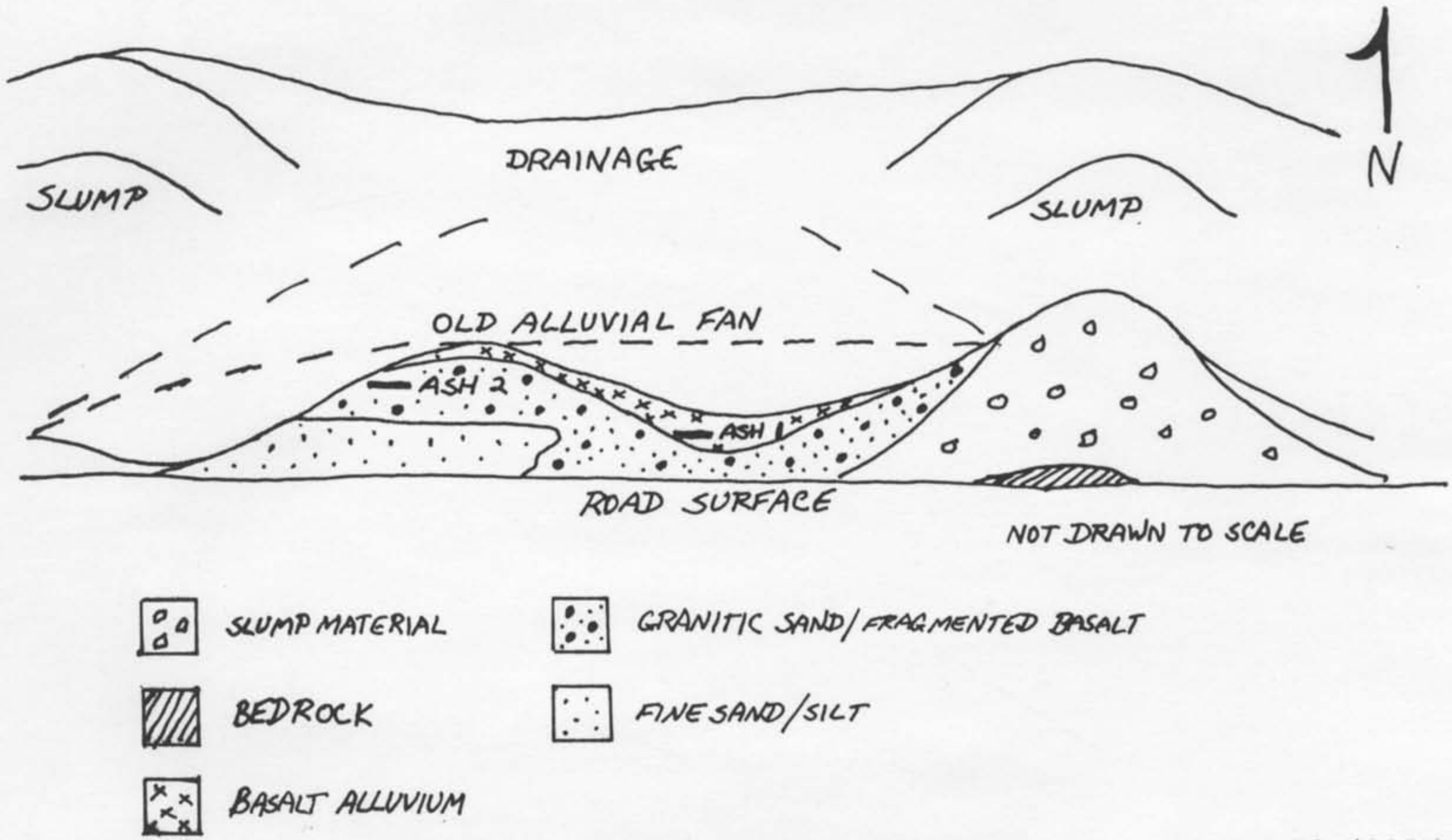


Figure 8.

Geomorphology of the road cut on the Vantage Highway (SE1/4, NW1/4, S24, T17N, R22E) two miles west of Vantage, Washington. This site appears to be at the base of an alluvial fan, between two old slumps. Tephra sample sites are marked Ash-1and Ash-2. Ash-1 is Mazama tephra dated at 6850 B.P. Ash 2 was likely a reworked tephra and contained glass shards of equal similarity to Mt. Saint Helens S (12,900 B.P.) and Cw (33,650-37,600 B.P.).

deposit below the basalt alluvium is less conclusive. Because there are no intervening stratigraphic layers between the basalt alluvium and granitic sand deposit, it is most likely that this deposit is late Wisconsin flood sediment.

The fine sand and silt sediment below the granitic sand deposit could be flood sediments or eolian deposits. This deposit appears to be massive in structure and lacks laminations, indicating that it is loess derived. A lack of buried paleosols may be the result of reworking by slumping or alluvial processes. Bedrock underlies the mass of unsorted basalt material that is apparently the result of the slump.

Characteristics of Flood Sediments

Flood sediments found in the research area include iceberg-rafted erratics, giant gravel bars, and laminated sand and gravel deposits. Giant gravel bars and laminated sand and gravel deposits were found only in close proximity to the main channel of the floods (within two miles). No slack-water sediments were discovered at elevations above 1100 feet. No flood sediments finer than sand were observed, with the possible exception of the sand/silt deposit at the Vantage Highway location. That deposit could be flood sediment or a reworked eolian deposit. The sand and gravel deposits found appear to best fit the description given by Baker (1973), who attributed the repetitious graded bedding to flood surges.

The giant gravel bars are formed close to the junction of the tributary valley and the main flood channel. These bars are composed of unsorted sand, gravel, and cobbles, and have a surface form reminiscent of giant ripple marks. These giant gravel bars best fit Baker's (1973) description of eddy bars. Further up the valley from the eddy bars, sand and gravel is deposited in repetitious laminated beds. No evidence could be found that these repetitious beds were the result of separate floods. There were no buried paleosols or loess deposits interstratified with the flood deposits, and no visible bioturbation or organic matter that would indicate a hiatus between floods.

Several possible explanations could account for the lack of fine slack-water sediments at elevations higher than 1100 feet. If the highest elevation erratics were deposited by flood surges rather than ponded flood water, the level of ponded water may have been closer to the 1100 foot elevation suggested by the flood deposited sand. If flood water was ponded at the 1200 foot elevation, it may have been for too short a time to allow for the settling of silts, or the drainages included in the study area may have been too small or too steep to allow for silt accumulation. Another possible explanation is that the series of significant periods of regional erosion and alluviation described by Cochran (1978) and Pavish (1973) could have removed evidence of fine sediments.

Other Findings

Other findings of this research include a possible correlation between the Missoula Floods and slumps. Old slumps and landslides were observed throughout the research area. Many of these features seemed to correspond closely to the 1200 foot elevation, suggested here as the maximum elevation reached by the flooding. This would be consistent with information presented by Grolier and Bingham (1978) who state that "landslides occurred during and immediately after the last glaciofluvial flooding". Areas of old slumps and landslides are visible as scarps above terraces, and/or hummocky topography, both on the air photos and from the ground. Large terraces formed by slumping often have smaller terraces and scarps above them. This subject warrants further research.

Conclusion

Mapping of the upper limits of the Missoula Floods achieved by this research indicates that the maximum elevation reached by the late Wisconsin floods in the Vantage area was 1200 feet. This elevation is based on the mapping of ice-rafted erratics, which were found to be the best indicator of maximum flood levels in the study area. Other flood deposits found in the study area were giant gravel bars and laminated sand and gravel deposits. Repetitious laminated sand and gravel deposits found in the study area best fit the description of turbidites deposited by flood surges, given by Baker (1973). Because there is no evidence of hiatus between floods, the repetitive sequences of laminated sand and gravel that were found in the research area do not provide evidence of multiple floods during the late Wisconsin episode of flooding. The lack of fine slack-water sediments at elevations higher than flood deposited sand is explained by several possibilities, including unsuitable conditions for initial deposition, or subsequent erosion. Although previous research indicates many episodes of flooding occurred prior to the late Wisconsin, tephra analysis provided no evidence that any of the flood sediments found in the research area were older than the late Wisconsin flooding episode.

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